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Low-rise buildings on shrinkable clay soils: Part 1

The need for additional guidance on building on clay soils was established by the concern at the high incidence of subsidence damage during the 1975-76 drought. This digest supplements Nos 63, 64 and 67 - Soils and foundations *- and is based on work done by BRE following the drought.*

The digest is published in three parts: Part 1 describes the shrinking and swelling behaviour of these soils and shows the general location within the UK of the more common shrinkable clays. It also gives guidance on identifying such clay and assessing its shrinking or swelling potential. Part 2 discusses designs which should provide stable foundations in the most adverse circumstances and Part 3 describes the design of bored pile and beam foundations.

Nature of clay soils

Soils which contain a large proportion of very small mineral particles (defined as having a diameter less than 0.002 mm and which are invisible to the naked eye) are called 'clays'. Clays are characteristically plastic, and smooth and greasy to the touch. The more clay in the soil, relative to any silt or other coarser-grained material, then the more pronounced are these characteristics.

In the wet state, clays are soft and sticky and require scrubbing to remove them from boots. When dried out, clays shrink and crack and intact lumps become very hard to break. When a clod of firm, shrinkable clay is immersed in water it will soften only slowly, without disintegrating. If the clod disintegrates quickly, it contains silt and other coarser-grained materials. In the field, firm shrinkable clays can be identified by their highly fissured nature, by the high polish left by digging tools and by the extensive crazing that occurs as the clay dries on the sunny side of a trench.

While clays are recognised by the small size of their constituent particles, it is as much the type of mineral in these particles as their size that contributes to the behaviour of the clay. For example, the very 'clayey' minerals hold water within their molecular structure, much as jelly does, whereas some soils, such as rock flours containing clay-sized particles, only hold water between particles and do not exhibit clay-like behaviour; in particular, their dry strength is low. The clays which contain the very 'clayey' minerals are called 'fat' clays and in nature they always hold more water than the 'lean' clays which contain fewer of the 'clayey' minerals.

Engineers use simple, standardised, mechanical index tests (BS 1377) to identify the clay-nature and plasticity of soils. In the first test, water is progressively added and thoroughly mixed into the soil to form a smooth paste. Each successive mix becomes weaker until the consistency may be described as 'liquid' when measured by a mechanical device. The amount of water (expressed as a percentage of the dry weight) in the clay at this 'liquid' consistency is called the Liquid Limit; the higher the Liquid Limit, the more 'clayey' the behaviour.

The Liquid Limit defines the amount of water required to bring the clay to a very weak, plastic consistency. At the other extreme is the Plastic Limit, which is the amount of water in a clay soil below which it is no longer plastic and pasty, but breaks up when worked in the hands. Below the Plastic Limit there is insufficient water to fill the spaces between the solid particles and increasingly the voids become filled with air as the water content reduces. A simple, standard test to determine the Plastic Limit is described in BS 1377. The range of water contents over which the soil behaves plastically therefore lies between the Plastic and Liquid Limits. Within this range the soil is saturated with water which lubricates and separates the solid particles. At these water contents the soil shrinks as it dries and the volume change is in direct proportion to the amount of water removed (see Fig 1). However, when soil at water contents near the Plastic Limit is dried, air enters the soil and the volume shrinkage becomes less than the amount of water removed.

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Occurence and identification of shrinkable clays in the UK

Firm, shrinkable clays, capable of supporting buildings of up to three or four storeys on shallow foundations, occur widely in the SE of England, as shown on the map in Fig 2. Examples of these clays are London, Gault, Weald, Kimmeridge, Oxford, Woolwich and Reading, Lias, Barton and the glacial drift clays, for example the chalky boulder clays of E Anglia, that are derived from the above-mentioned clays by glaciation. When originally laid down under water, these clays existed with moisture contents above the Liquid Limit. In the ensuing millions of years, the clays slowly consolidated as the imposed loads of soil overburden and glaciation squeezed the water out of the soil.

Many of the clays encoutered in SE England are termed 'overconsolidated' because great thicknesses of soil have been eroded with time leaving soils which have been consolidated by loads far greater than they now experience in the ground. In consequence, these clays often exist normally in the fully saturated condition, at moisture contents close to the Plastic Limit, ie typically 25 to 30 per cent for London Clay. However, close to the ground surface, in the top 1 - 1.5 m, fluctuations in moisture content from as little as 15 per cent in dry summer weather to 40 per cent in wet winters frequently occur.

Some shrinkable clays occur further north than the areas indicated in Fig 2; for example, those derived from the weathering and glaciation of Carboniferous shales around Sunderland and north of Shrewsbury. However, in the North the surface clays are generally sandy and their potential shrinkage is, therefore, smaller. In addition to the firm clays, there are soft, alluvial clays found in, and adjacent to, estuaries, lakes and river courses. Examples of these are the Fens, the Somerset levels, the Kent and Essex marshes alongside the Thames, and the clays of the Firths of Forth and Clyde. All these clays have a firm, shrunken crust which is drier than the body of the clay beneath. The foundation problems in these areas are not only of clay shrinkage, but also of avoiding excessive settlement due to loading the underlying softer clay and peat. Figure 2 gives only a general indication of the location of shrinkable clays; more detailed information on the location and identification of clay soils should be obtained from the Geological Survey maps and accompanying memoirs.

Shrinkage and swelling of clay soils

As the water content of a clay soil is reduced below its 'natural state' the soil will shrink. As the soil dries and shrinks, the soil moisture exerts more and more suction. If water is then brought into contact with the soil, it is absorbed as the soil swells. The concept of soil moisture suction in relation to moisture content is important when considering the influence of trees and other large vegetation on shrinkable clays.

The only way in which clay volume change can occur, other than as a result of load change, is through change in its moisture content. This can be brought about in two ways: one is through moisture movement near the ground surface where moisture evaporates in dry weather and is replenished by rainfall and by upward migration from the water table. The other way is by transpiration of soil moisture from greater depths than the first process, through the action of the roots of vegetation. In general the larger the vegetation, the greater will be its demand for moisture in dry weather.

Research at BRE has shown that, with the exception of the ground around large trees, and possibly hedges and large shrubs, the seasonal volume changes due to the presence of vegetation extend only about 1 - 1.5 m

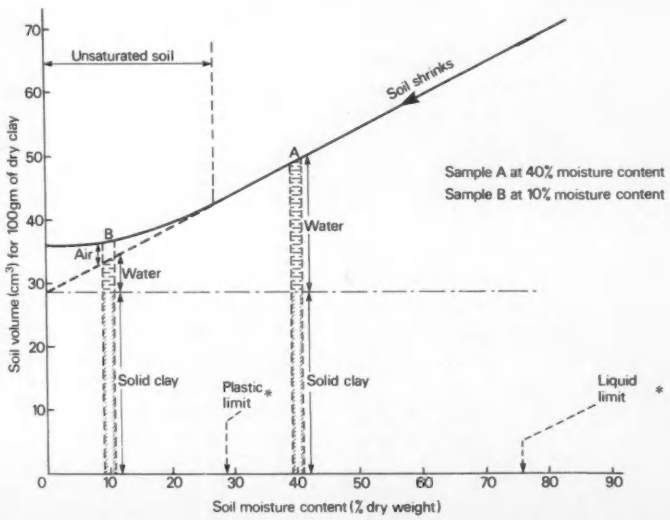

Fig 1 Clay soil shrinkage
*Typical values for a clay with potential very high shrinkage

into the clay ground. Significant clay shrinkage and swelling is confined to the top 1m or so.

However, large trees can create deep zones of dried and shrunken clay beneath them. In a dry summer, the zones will extend and when the wet weather returns the slow rate of penetration of water into the more impermeable dry clay will be insufficient to replenish the soil before the next summer arrives. Thus the larger dry zone becomes permanent.

For practical purposes then, serious drying of clay soils in the UK, to depths in excess of 1 to 1.5 m is almost always associated with the removal of moisture by tree roots. The amount of shrinkage or swelling that a clay will undergo is not easy to determine. The change in volume will depend on the localised clay properties (clay content and mineralogy) and the soil moisture changes that occur. The most useful way of assessing soil volume changes is to measure ground movements on site but, since the moisture changes are brought about by seasonal climatic changes, a considerable period of time is required. This approach is clearly impractical.

A practical alternative is to measure the shrinking and swelling of a sample taken from the site. In the case of shrinkage this approach is simple. A block of clay is removed, trimmed to have smooth sides and allowed to dry slowly at room temperature for two to three weeks. Comparison of linear measurements before and after drying give an estimate of the in-situ shrinkage. The block will probably dry out to a greater extent than will the clay on site so that the prediction will be an over-estimate. The measurement of sample swelling is not normally available as a practical test and because of its relative complexity remains a research tool.

Another approach to predicting shrinkage and swelling is the indirect method of determining the *potential* to shrink or swell. This involves examining properties of the clay that can be obtained from simple, standard classification tests. These properties are the Plasticity Index and the percentage clay content or clay fraction* of the soil. The Plasticity Index is obtained by substracting the Plastic Limit from the Liquid Limit.

Tests to determine these properties are specified in BS 1377 and are readily available from a competent soil testing laboratory at little cost.

In Table 1, Plasticity Index and clay fraction have been used to indicate the potential of a soil to shrink or swell. The figures have been obtained from many different sources and frequently overlap. Since a set of soil properties will often not fit neatly into one category, the determination of shrinkage potential requires some judgement.

* Percentage of the soil with particle size less than 0.002 mm.

Fig 2 General distribution of firm shrinkable clays - based on BRE records and Institute of Geological Sciences maps

Table 1 Clay shrinkage potential

Plasticity Index %	Clay fraction %	Shrinkage potential
> 35	> 95	Very high
22 - 48	60 - 95	High
12 - 32	30 - 60	Medium
< 18	< 30	Low

To give an indication of how Table 1 may be used, the shrinkage potential of some clays commonly found in the UK is given in Table 2. It should be remembered that the properties of a clay can vary considerably from site to site.

Table 2 Shrinkage potential of some common clays

Clay type	Plasticity Index %	Clay fraction %	Shrinkage potential
London	28	65	Medium/high
London	52	60	High
Weald	43	62	High
Kimmeridge	53	67	High/very high
Boulder	32	-	Medium
Oxford	41	56	High
Reading	72	-	Very high
Gault	60	59	Very high
Gault	68	69	Very high
Lower Lias	31	-	Medium
Clay silt	11	19	Low

Foundation design and performance in shrinkable clays

The design of foundations for low-rise buildings must take account of the shrinkage and swelling behaviour of clays, as the moisture content varies according to climatic and vegetation conditions. In practice, two courses of action are open: firstly, to estimate the potential to swell or shrink and then to try to avoid events which cause changes in moisture content; or secondly, to accept that swelling or shrinkage will occur and to take account of this in design. The foundations can be designed to resist resulting ground movements, or the superstructure designed to accommodate movement without damage.

Work carried out by the Building Research Establishment indicated a minimum foundation depth requirement of 0.9 m, below which seasonal wetting and drying and the influence of minor vegetation produce no significant ground movement. This depth has now become the accepted minimum for foundations on all clay soils. The research further identified the influence that roots of large trees may have in removing moisture from clay beneath foundations. This may cause subsidence leading to structural damage in dry weather conditions. The design of foundations suitable to withstand the larger movements sometimes induced by root action is discussed in Part 2 of this digest.

Further reading

BRE Digests
63 Soils and foundations: Part 1
64 Soils and foundations: Part 2
67 Soils and foundations: Part 3

British Standards
BS 1377:1975 Methods of test for soil for civil engineering purposes
BS 5837:1980 Trees in relation to construction

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